# Mercury Radar Ranging Data from 1987 to 1997

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## ABSTRACT

This is a brief report on radar ranging data to the subradar point on Mercury. This report makes available ten years of such data, from 1987 to 1997.

*Subject headings:* Solar System: planets and moons: Mercury; ephemerides

## 1. Introduction

An observational program to obtain radar ranging data to the planet Mercury using the Deep Space Network's 70-m antenna at Goldstone, CA, has been underway since 1987. These observations at Goldstone have utilized the same basic data acquistion hardware and software throughout this period, and have been reduced with a single set of data analysis software . The purpose of this short note is to document these ranges. A longer paper is in preparation which describes the details and difficulties of the data acquisition and analysis, as well as the geophysical implications of the topography and images of Mercury's equatorial zone.

## 2. Observations

Discussions of data used in the planetary ephemerides have been previously published (Standish, 1990; Standish et al., 1992). Those data include Mercury radar ranging from 1966 to 1974. These new data have almost nothing in common with the Mercury radar data incorporated in these previous ephemerides, except that some of the data were taken from roughly the same location in the Mojave desert using an antenna which evolved into the present observatory.

The data below are round-trip delays from Goldstone to the sub-radar point on Mercury, with the epoch of the time tag being the time the echoes were received at Goldstone. No corrections of any sort have been applied to these data, including no attempt to model the propagation delay due to the interplanetary plasma.

Table 1 below lists the data. Attention should be paid to the various frequencies of operation. In particular, note that two different center frequencies near 8500 MHz have been used: 8495 MHz and 8510 MHz.

Table 1. Mercury Ranging 1987-1997

| year yyyy mm dd | UTC time hr:mn:sc | measured Range in us | adjusted sigma | MHz freq | resid in us DE-405 | formal err us | error ratio |
|---|---|---|---|---|---|---|---|
| 1987 07 08 | 18:20:00 | 588423949.5 | 3.000 | 8495. | 1.68 | ... | ... |
| 1987 07 11 | 17:50:04 | 617845043.3 | 0.441 | 2320. | -1.44 | 0.16 | 2.68 |
| 1987 07 12 | 22:35:32 | 632547417.8 | 0.133 | 8495. | 2.75 | 0.08 | 1.59 |
| 1987 07 18 | 17:29:09 | 724802968.2 | 0.267 | 8495. | -6.32 | 0.04 | 6.43 |
| 1987 07 20 | 17:18:41 | 763938751.5 | 0.193 | 8495. | -1.65 | 0.11 | 1.72 |
| 1988 06 10 | 16:20:00 | 551547833.7 | 4.000 | 2320. | 0.40 | ... | ... |
| 1988 06 26 | 17:18:46 | 660747282.7 | 0.447 | 2320. | -2.78 | 0.04 | 10.68 |
| 1988 06 27 | 14:27:44 | 674033447.1 | 0.212 | 2320. | 2.83 | 0.05 | 3.87 |
| 1988 06 29 | 00:08:16 | 696472298.4 | 0.308 | 8495. | -9.74 | 0.07 | 4.28 |
| 1989 04 30 | 16:06:09 | 858564585.9 | 7.494 | 8495. | 2.07 | 0.33 | 22.91 |
| 1989 05 22 | 19:02:40 | 550931324.6 | 0.266 | 8495. | 6.52 | 0.08 | 3.36 |
| 1990 04 25 | 23:10:35 | 626316657.9 | 1.157 | 8495. | -9.80 | 0.16 | 7.18 |
| 1990 05 18 | 18:05:23 | 634467018.0 | 2.125 | 8495. | 15.03 | 0.09 | 22.90 |
| 1990 08 07 | 01:10:22 | 978444953.1 | 0.162 | 8495. | 5.08 | 0.12 | 1.33 |
| 1990 09 12 | 22:10:58 | 683856250.1 | 0.371 | 8495. | -12.20 | 0.06 | 6.20 |
| 1990 09 21 | 22:21:21 | 885734458.4 | 1.023 | 8495. | 0.88 | 0.07 | 15.32 |
| 1991 09 07 | 21:40:52 | 933821387.2 | 0.559 | 8510. | -3.90 | 0.14 | 4.12 |
| 1991 12 07 | 20:04:10 | 677658671.6 | 0.370 | 8510. | 1.95 | 0.02 | 22.50 |
| 1991 12 08 | 20:55:06 | 677062699.1 | 0.443 | 8510. | -0.86 | 0.03 | 16.82 |
| 1992 02 16 | 23:23:41 | 1355558771.0 | 0.673 | 8510. | 6.49 | 0.09 | 7.51 |
| 1992 03 24 | 16:29:43 | 615775574.3 | 1.381 | 8510. | -13.46 | 0.10 | 14.22 |
| 1992 03 25 | 16:35:30 | 607791928.9 | 0.420 | 8510. | -14.12 | 0.14 | 3.05 |
| 1992 04 14 | 19:08:45 | 720618943.2 | 0.632 | 8510. | -1.39 | 0.03 | 24.19 |
| 1993 02 24 | 22:03:09 | 835906073.9 | 0.262 | 8510. | -0.06 | 0.02 | 15.06 |
| 1993 04 03 | 17:18:01 | 848769267.2 | 0.420 | 8510. | -5.04 | 0.05 | 8.38 |
| 1993 04 12 | 17:25:51 | 980176134.7 | 0.461 | 8510. | -4.41 | 0.03 | 18.37 |
| 1993 04 14 | 17:59:45 | 1009435075.3 | 0.331 | 8510. | -12.73 | 0.04 | 7.74 |
| 1993 04 17 | 19:34:56 | 1053282390.8 | 0.178 | 8510. | -7.10 | 0.04 | 4.54 |
| 1993 07 19 | 16:52:17 | 604669060.0 | 0.089 | 8510. | 2.36 | 0.02 | 3.62 |
| 1993 07 25 | 17:33:54 | 683918721.3 | 0.964 | 8510. | -8.24 | 0.04 | 22.27 |
| 1993 07 26 | 15:09:31 | 699435983.9 | 0.353 | 8510. | -14.63 | 0.06 | 5.81 |
| 1993 07 27 | 16:49:11 | 718995576.4 | 1.808 | 8510. | -9.06 | 0.05 | 38.00 |
| 1994 01 15 | 21:46:43 | 1354576803.5 | 0.118 | 8510. | 6.78 | 0.08 | 1.55 |
| 1994 01 25 | 22:15:16 | 1200215600.7 | 0.566 | 8510. | -7.75 | 0.21 | 2.66 |
| 1994 02 07 | 22:29:38 | 868372045.9 | 1.223 | 8510. | 10.03 | 0.06 | 20.68 |
| 1994 03 06 | 19:31:55 | 736326439.1 | 0.315 | 8510. | 7.35 | 0.04 | 7.21 |
| 1994 03 11 | 18:45:34 | 807523426.8 | 0.230 | 8510. | 8.18 | 0.05 | 4.28 |
| 1994 06 14 | 16:38:25 | 597770011.9 | 1.471 | 8510. | -1.54 | 0.14 | 10.38 |
| 1994 06 16 | 22:00:00 | 579670580.7 | 3.000 | 8510. | -4.00 | ... | ... |
| 1994 07 11 | 17:39:46 | 734255721.7 | 3.000 | 8510. | -8.40 | ... | ... |
| 1994 07 22 | 14:40:34 | 975737105.7 | 1.122 | 8510. | 2.45 | 0.06 | 19.90 |
| 1994 10 10 | 18:27:40 | 745813234.7 | 1.370 | 8510. | 5.68 | 0.06 | 24.13 |
| 1994 10 11 | 19:25:22 | 730521393.4 | 0.613 | 8510. | 6.37 | 0.04 | 15.09 |
| 1994 10 16 | 18:09:35 | 675502767.7 | 0.535 | 8510. | 4.08 | 0.05 | 10.27 |
| 1994 11 08 | 16:56:40 | 1057708676.1 | 0.428 | 8510. | -4.51 | 0.06 | 7.45 |
| 1995 02 24 | 19:32:14 | 879366834.5 | 1.332 | 8510. | 2.25 | 0.03 | 41.73 |
| 1995 05 24 | 18:08:41 | 619576469.8 | 0.465 | 8510. | -13.10 | 0.07 | 6.31 |

TABLE 1. (continued)

| year yyyy mm dd | UTC time hr:mn:sc | measured Range in us | adjusted sigma | MHz freq | resid in us DE-405 | formal err us | error ratio |
|---|---|---|---|---|---|---|---|
| 1995 06 05 | 17:00:27 | 548334182.6 | 0.176 | 8510. | 2.01 | 0.03 | 6.58 |
| 1995 06 27 | 15:42:39 | 793888206.0 | 0.360 | 8510. | 4.09 | 0.05 | 7.21 |
| 1995 07 03 | 14:01:03 | 917653713.7 | 0.606 | 8510. | -0.83 | 0.07 | 9.32 |
| 1995 09 21 | 23:24:03 | 753406451.7 | 1.885 | 8510. | -0.42 | 0.10 | 19.14 |
| 1995 09 30 | 17:42:34 | 659406956.5 | 0.611 | 8510. | 0.94 | 0.05 | 11.19 |
| 1995 10 07 | 17:38:34 | 679426869.6 | 0.184 | 8510. | -13.27 | 0.02 | 8.35 |
| 1995 10 20 | 16:06:45 | 976541349.5 | 1.648 | 8510. | -6.48 | 0.07 | 22.69 |
| 1995 11 01 | 16:40:11 | 1257039483.5 | 1.968 | 8510. | -1.39 | 0.09 | 22.58 |
| 1996 02 03 | 20:21:52 | 845251858.1 | 0.180 | 8510. | 6.23 | 0.04 | 4.92 |
| 1996 02 06 | 20:23:24 | 897975665.3 | 0.442 | 8510. | 3.25 | 0.06 | 7.56 |
| 1996 02 22 | 20:11:56 | 1141705527.0 | 0.457 | 8510. | -5.01 | 0.03 | 15.52 |
| 1996 02 25 | 20:04:38 | 1178113036.9 | 0.847 | 8510. | -11.44 | 0.12 | 7.30 |
| 1996 02 27 | 20:05:42 | 1200771937.4 | 0.698 | 8510. | -7.89 | 0.06 | 12.06 |
| 1996 03 31 | 18:59:49 | 1316523201.5 | 0.746 | 8510. | -6.41 | 0.09 | 8.09 |
| 1996 04 15 | 23:00:00 | 1039181314.3 | 3.000 | 8510. | 5.00 | ··· | ··· |
| 1996 04 21 | 22:26:09 | 890680111.4 | 1.081 | 8510. | 13.43 | 0.05 | 20.34 |
| 1996 04 27 | 21:57:57 | 755547130.2 | 0.242 | 8510. | 8.78 | 0.03 | 8.65 |
| 1996 05 03 | 19:29:08 | 649837243.3 | 0.216 | 8510. | 3.11 | 0.02 | 13.09 |
| 1996 05 14 | 21:10:05 | 552860708.0 | 0.321 | 8510. | -3.75 | 0.04 | 8.05 |
| 1996 05 27 | 15:41:37 | 613622222.4 | 0.699 | 8510. | 4.16 | 0.02 | 30.83 |
| 1996 06 26 | 16:24:50 | 1146729512.8 | 1.590 | 8510. | 1.17 | 0.13 | 11.89 |
| 1996 09 23 | 17:48:56 | 719139029.0 | 0.349 | 8510. | -10.59 | 0.03 | 10.79 |
| 1996 10 09 | 16:10:00 | 1131083005.9 | 3.000 | 8510. | -10.44 | ··· | ··· |
| 1997 04 15 | 01:27:44 | 696383625.1 | 4.000 | 8510. | -5.70 | ··· | ··· |
| 1997 04 20 | 23:15:56 | 598410718.3 | 0.202 | 8510. | 6.35 | 0.03 | 7.92 |
| 1997 04 23 | 23:50:47 | 574801625.5 | 0.478 | 8510. | 2.11 | 0.04 | 13.45 |
| 1997 04 25 | 23:34:54 | 566103253.8 | 0.462 | 8510. | -12.54 | 0.03 | 13.40 |
| 1997 04 27 | 23:34:24 | 562650227.5 | 0.144 | 8510. | -6.40 | 0.03 | 4.66 |
| 1997 05 05 | 21:55:54 | 594680092.6 | 0.231 | 8510. | 0.02 | 0.04 | 6.32 |
| 1997 05 28 | 21:12:36 | 921462511.4 | 0.327 | 8510. | 0.43 | 0.11 | 3.09 |
| 1997 07 18 | 01:05:02 | 1126002051.5 | 0.880 | 8510. | 12.33 | 0.07 | 13.35 |
| 1997 08 10 | 01:48:10 | 806381241.6 | 1.029 | 8510. | 1.42 | 0.18 | 5.78 |

## A. Appendix A: More about the data processing

All observations were made with an effective pulse resolution of 4 microseconds over-sampled by a factor of two (i.e. two samples for code symbol). Thus, the effective resolution is near 300 meters. All data were processed into two dimensional delay-Doppler images with an effective frequency resolution of 0.94 Hz. Images were normally integrated for one round-trip-cycle unless this would cause significant smearing of the image, in which case, we integrated for a shorter period. The data reported in the table were usually taken form the output of an automatic fitting program that follows a selected set of longitudes creating a topographic strip map along the apparent rotation equator. However, in a few cases, the range estimates were made by hand, and these are indicated by the lack of values for the last two columns of the table which are estimates from the fitting program. The adjusted standard error incorporates both a formal error estimate and an estimate based on range estimates in six adjacent longitude slices. This estimate tends to provide some compensation for errors caused by local topography. We measured all ranges with respect to the JPL DE-405 ephemeris during the final processing, and the 6th column of the table reflects these residuals. The next column gives a formal error estimate that does not include feature noise in the estimate, however, the last column gives a measured error ratio that can be used to apply a realistic correction to the previous column. In general, the higher the signal power to thermal noise power and the more complex the topography, the larger the corection will be. The adjusted sigma will normally not be smaller than the product of the last two column entries, and it will normally be greater if the topography near the sub-radar point is complicated or sloping. In some cases, the sub-radar point was sufficinetly complex that the automated program failed to find a reasonable range. In such cases, we measured the range by a human examining the data and attached an adjusted sigma that bounded our uncertainty.

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